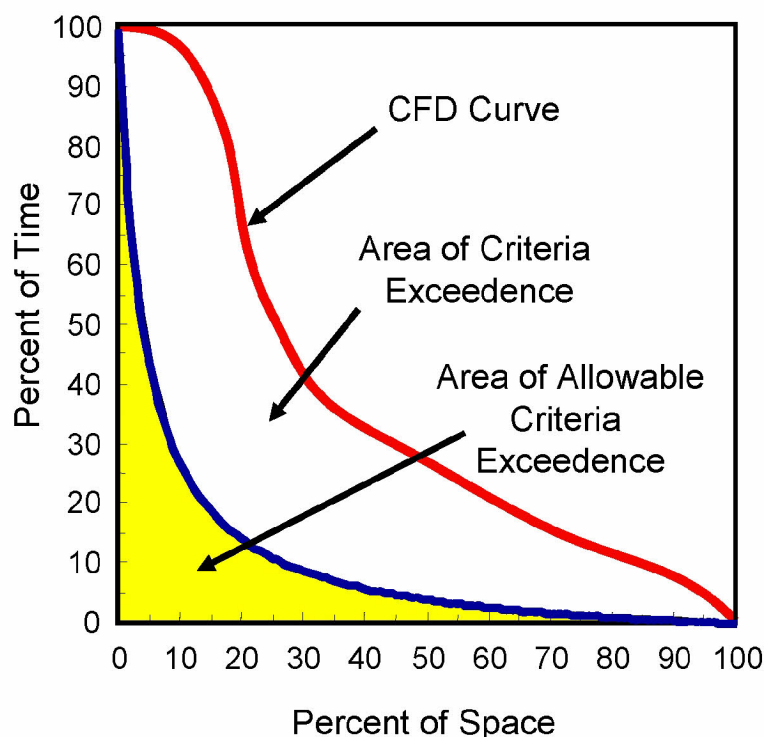


### Appendix I. Documentation of the Reduced Sensitivity to Load Reductions at Low Nonattainment Percentages

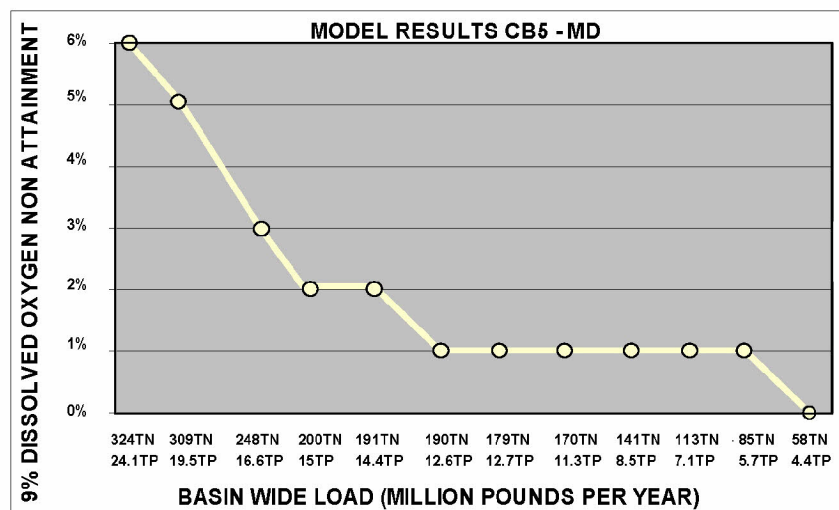
The Chesapeake Bay water quality criteria adopted by the four Bay jurisdictions into their respective water quality standards (WQS) regulations provide for allowable exceedances of each set of dissolved oxygen (DO), water clarity and chlorophyll *a* criteria defined through application of a biological or default reference curve (USEPA 2003). Figure I-1 depicts this concept in yellow as allowable exceedance of the criterion concentration. To compare the Chesapeake Bay Water Quality Model results with the Bay jurisdictions WQS, the model results for each scenario and for each modeled segment are analyzed to determine the percent of time and space that the modeled DO results exceed the allowable concentration. For any modeled result where the exceedance in space and time (shown in Figure I-1 as the red line) exceeds the allowable exceedance (shown in Figure I-1 as the yellow area), that segment is considered in nonattainment. That amount of nonattainment is shown in the figure as the area in white between the red line and the yellow area and is typically displayed in model results as percent of nonattainment for that segment. The amount of nonattainment is reported to the whole number percent. The yellow area below the blue reference curve reflects the amount of *allowable* criteria exceedance. The area between the blue reference curve and the red cumulative frequency distribution (CFD) curve is the amount of *unallowable* criteria exceedance, defined here as the *red area*.



Source: USEPA 2003

**Figure I-1. Illustration of the application of a reference curve to the cumulative frequency distribution curve to assess Chesapeake Bay water quality criteria attainment.**

Figure I-2 below displays Chesapeake Bay Water Quality Model results showing percent nonattainment of the 30-day mean open-water DO criterion of the Maryland portion of the lower central Chesapeake Bay segment CB5MH\_MD for various basinwide nitrogen and phosphorus loading levels.



Source: Appendix M

**Figure I-2. Example of DO criteria nonattainment results from a wide range of total nitrogen (TN) and total phosphorus (TP) loading Chesapeake Bay Water Quality Model scenarios.**

As can be seen in Figure I-2, there is a notable improvement in the percent DO criterion nonattainment as the loads are reduced until approximately 1 percent nonattainment. At and below a basinwide loading level of 190 million pounds per year total nitrogen (TN) and 12.7 million pounds per year total phosphorus (TP), the 1 percent nonattainment is persistent through consecutive reductions in loading levels and remains consistent until a loading level of 58 million pounds per year TN and 4.4 million pounds per year of TP is reached. While this is one of the more extreme examples of persistent levels of 1 percent nonattainment over a wider range of reduced nitrogen and phosphorus loads, this general observation of persistent nonattainment at 1 percent is fairly common to the Bay Water Quality Model DO results as described and documented below.

Clear evidence of small, yet persistent percentage of model projected DO criteria nonattainment over a wide range of reduced nitrogen and phosphorus loads across a wide range of segments and designated uses, all of which are responding to nitrogen and phosphorus load reductions, is documented within this appendix. Given that this has been observed in a wide variety of different segments across all three designated uses—open-water, deep-water, and deep-channel—nonattainment percentages projected by the Bay Water Quality Model rounded to 1 percent were considered to be in attainment for a segment’s designated use for purposes of developing the Chesapeake Bay TMDL.

A separate validation of the findings described above was undertaken to confirm that 1 percent was the correct percentage below which the designated use-segment could be considered in attainment and is provided in this appendix.

## Reporting of Criteria Nonattainment Percentages

Chesapeake Bay modeling results for DO, chlorophyll *a*, and water clarity criteria nonattainment percentages are rounded to whole numbers. This is a common scientific practice and principle for conveying data to the public and is fully consistent with how many others report modeling output.

## Documenting Attainment for 1 Percent Nonattainment Criteria Values

The Chesapeake Bay water quality criteria adopted by Maryland, Virginia, Delaware, and the District of Columbia into their respective WQS regulations already provides for *allowable* exceedances of each set of DO, water clarity and chlorophyll *a* criteria defined through application of a biological or default reference curve (USEPA 2003). What is being addressed here is how to address 1 percent nonattainment DO, water clarity, and chlorophyll *a* criteria values assessed using the CFD-based criteria assessment procedures in the face of clear evidence: (1) for persistence over large simulated load reductions across numerous segments and designated uses; and (2) reduced sensitivity to load reductions at and below the 1 percent nonattainment level.

## Evaluation of Residual 1.499 Percent or Less DO Criteria Nonattainment Values

There is clear evidence for a *residual* of 1 percent DO criteria nonattainment across a large span of model-simulated load reductions across a number of tidal Bay segments and designated uses (Table I-1). Within the Bay TMDL document and supporting appendices, the reported criteria attainment values already account for the allowable exceedances documented in each Bay jurisdiction's respective Chesapeake Bay WQS regulations. These reported criteria attainment values also account for any restoration variances adopted by the Bay jurisdictions into their WQS regulations. All the values that are colored green denote full attainment of the respective criteria, DO in this case.

For illustration purposes only, as observed in the DO *stoplight plot* spreadsheet dated May 24, 2010, shared with members of the Chesapeake Bay Program's Water Quality Goal Implementation Team, 21 designated use-segments have the recorded model scenario-transformed monitoring data nonattainment values between 0.0 percent and 1.5 percent across a range of model scenarios. (Note that all the values reported in Table I-1 would round to 0 percent or 1 percent.) Those model scenarios had loading levels that spanned 9 to 151 million pounds of nitrogen and comparable ranges of phosphorus loading levels (Table I-1).

**Table I-1. The range of DO criteria nonattainment percentages across different model simulated nitrogen load ranges for 21 Chesapeake Bay segments-designated uses**

Chesapeake Bay segment	Designated use	Criteria nonattainment range <sup>a</sup> (%)	Model simulated nitrogen load range (million pounds/yr)
CB7	Open-water	0.5-0.0	200-141
CHOMH1	Open-water	0.1-0.0	254-179
CSHMH	Open-water	0.8-0.1	342-309
DCATF	Open-water	1.2-0.1	191-179
PAXTF	Open-water	1.0-0.6	190-179
DCPTF	Open-water	0.6-0.2	309-254
MAGMH	Open-water	1.3-0.3	342-191
MOBPH	Open-water	1.0-0.0	342-200
PIAMH	Open-water	0.1-0.1	191-179
TANMH	Open-water	1.5-0.1	342-309
YRKMH	Open-water	1.0-0.4	191-170
CB3MH	Deep-water	0.6-0.0	254-179
CB5MH	Deep-water	1.5-0.0	254-141
CHSMH	Deep-water	0.5-0.4	170-141
EASMH	Deep-water	0.8-0.2	200-170
MD5MH	Deep-water	1.5-0.1	191-141
MAGMH	Deep-water	0.5-0.5	170-141
PATMH	Deep-water	1.1-0.1	200-190
VA5MH	Deep-water	0.7-0.0	254-179
CB3MH	Deep-channel	0.2-0.1	200-190
EASMH	Deep-channel	1.3-0.0	190-170

Source: The DO criteria attainment detailed stoplight spreadsheet dated May 24, 2010 presented to the Chesapeake Bay Program's Water Quality Goal Implementation Team during the Team's May 24, 2010, conference call.

Note:

a. Each 0.0% value in this column is colored in red in the original May 24, 2010 stoplight plot spreadsheet, denoting a very low percentage of nonattainment was recorded below 0.1%.

Small, yet persistent percentage of DO criteria nonattainment are observed across a wide range of segments and designated uses, all of which are responding to nutrient load reductions. There is not comparable evidence of persistent percentages of DO criteria nonattainment above 1 percent across a wide range of segments and designated uses for segments responding to nutrient load reductions. Several open-water segments exist where the same percentage nonattainment persists across a wide set of nutrient loading reductions—e.g., Gunpowder River (GUNOH) at 5 percent from 342 TN to 85 TN, Wicomico River (WICMH) at 5 percent from 191 TN to 85 TN, several segments in Pocomoke River at 5 percent from 179 TN to 85 TN (see Appendix M). However, all those segments have been identified as having poor local responses to load reductions in the Bay Water Quality Model scenarios on the basis of poor linear regressions. Other lines of evidence, separate from the model-generated outputs were used to determine attainment and develop the respective Bay segment TMDL (see Appendix N). The cause for the persistent percentages (poor linear regressions) is different from the small, yet persistent percentages (reduced sensitivity when approaching water quality criteria attainment) being addressed in this appendix.



### ***Analysis of DO Criteria Attainment Sensitivity to Simulated Load Reductions***

A separate validation of the findings described above was undertaken to confirm that 1 percent was the correct percentage below which the designated use-segment could be considered in attainment. This analysis involves plotting the change in unallowable DO criterion exceedance or *red area* under the reference curve (see Figure I-1) per loading unit against the starting red area. The change in red area between two scenarios is divided by the change in load. For this analysis, the changes in nitrogen (*N*) and phosphorus (*P*) loads are combined into a single measure, load units, enabling the calculation of change in red area per change in load:

$$\text{load units} = (N + 10 \times P) / 2 \quad \text{Equation I-1}$$

This single measure, when plotted against starting red area, allows a direct comparison of sensitivity of the analysis system<sup>1</sup> to nitrogen and phosphorus load changes across different levels of nonattainment. To get a true sensitivity, calculations involving scenarios that attained the applicable DO criteria were not included. Twelve scenarios were used with eight 3-year periods for a total of 96 possible sensitivity assessments per designated-use segment, decreased by the number of assessments that attained the applicable DO criterion.

This analysis was not amenable to tidal tributary segments as the nitrogen and phosphorus loadings are basinwide and not specific to an individual tidal tributary. Further, some of the existing scenarios used for this analysis have varying levels of nitrogen and phosphorus load reductions between different tributaries.

The CB7PH open-water segment provides a clear example of a decrease in sensitivity to nitrogen and phosphorus load reductions as criteria nonattainment approaches zero. The highest sensitivity to load reductions is with the highest red area, but there is still considerable sensitivity to nitrogen and phosphorus load reductions through approximately 0.2 percent (Figure I-3). Another example is the CB2OH open-water segment, where a sharp drop off occurs in sensitivity to nitrogen and phosphorus load reductions near 1 percent (Figure I-4).

A counter-example is the CB5MH open-water segment, where the sensitivity to load reductions is relatively constant throughout the model-simulated range of load reductions (Figure I-5).

A large number of segments could be analyzed (see Table I-1), but it is most appropriate to focus on those designated-use segments most important to the Bay TMDL—those requiring significant basinwide nutrient reductions to come in attainment with the respective DO criterion. Those designated use-segments are CB3MH, CB4MH, and CB5MH for deep-water and deep-channel and POTMH for deep-channel.

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<sup>1</sup> The analysis system referred to here is the combination of the Chesapeake Bay Water Quality and Sediment Transport Model, the procedures for using differences in Bay model scenarios outputs to transform Bay water quality monitoring data, and the EPA-published Bay criteria assessment procedures.

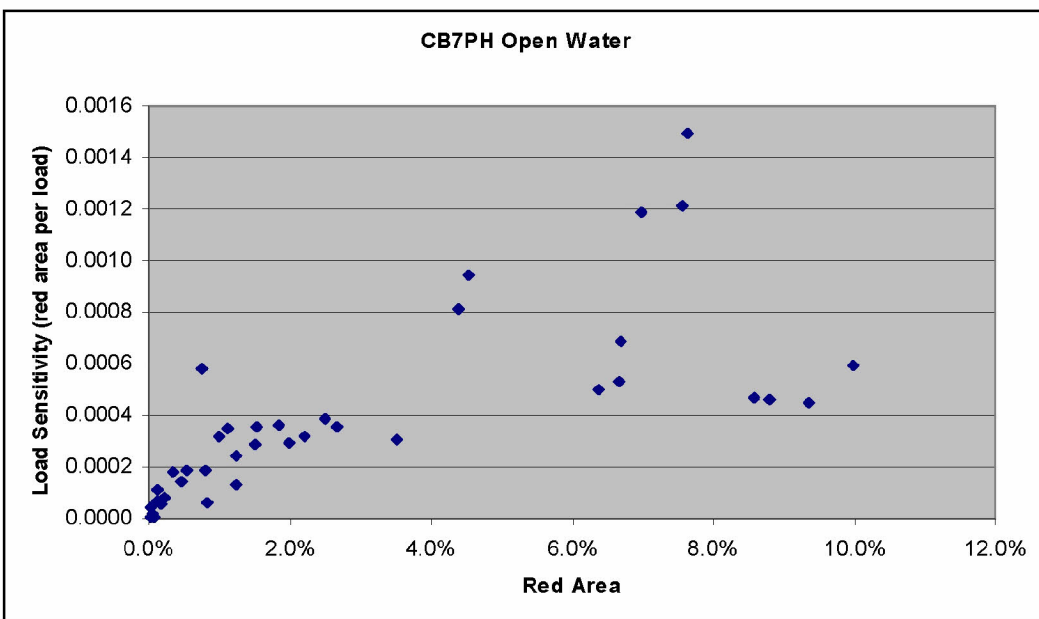


Figure I-3. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB7PH open-water.

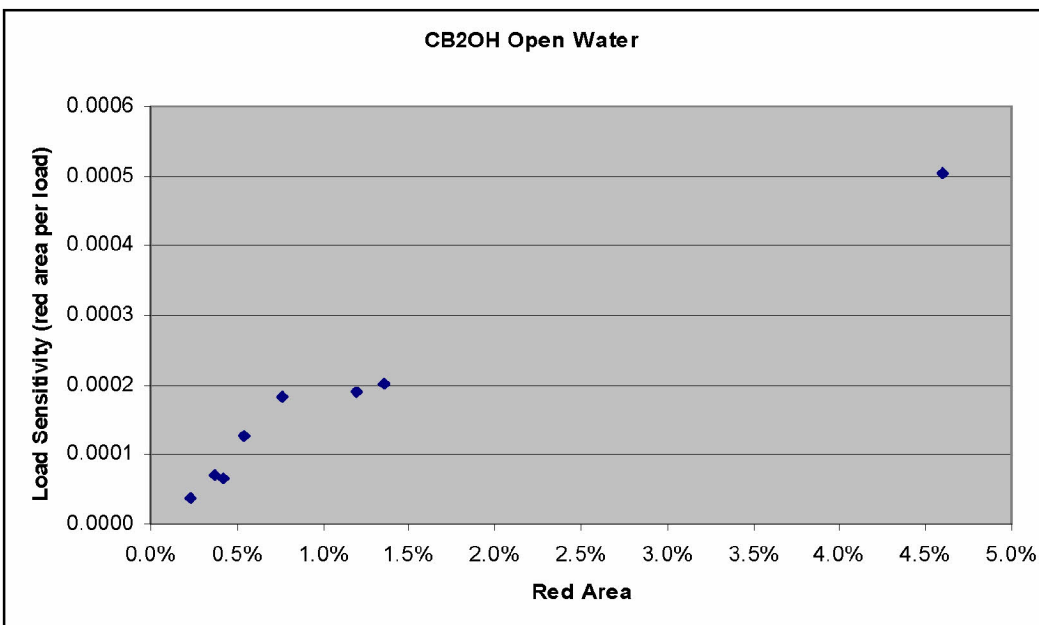


Figure I-4. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB2OH open-water.

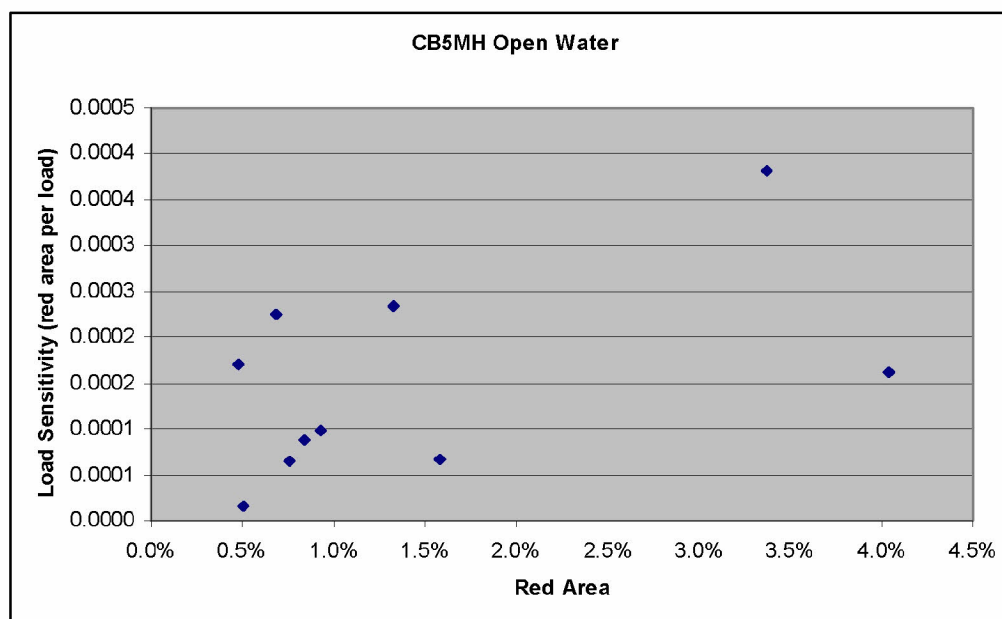


Figure I-5. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB5MH open-water.

The CB3MH deep-water segment has consistently reducing sensitivity to nitrogen and phosphorus load reductions and no high sensitivity examples above 1 percent red area (Figure I-6). The CB4MH deep-water designated use-segment shows relatively consistent sensitivity across a wide range of red area (Figure I-7). The CB5MH deep-water designated use-segment (Figure I-8) and the POTMH deep-water designated use-segment (Figure I-9) are relatively constant across wide ranges but have a clear reduction in sensitivity to load reductions around 1 percent.

The deep-channel designated use-segment plots are similar to the deep-water designated use-segment plots. The CB3MH deep-channel designated use-segment also shows a consistent range of sensitivity throughout multiple ranges of red area but has low sensitivity to further load reductions at 1–1.5 percent red area (Figure I-10). The CB4MH deep-channel designated use-segment shows a clear drop off in sensitivity to load reductions at 1 percent (Figures I-11 and I-12). The CB5MH deep-channel designated use-segment has no basis to make the judgment because no red area values are less than 15 percent (Figure I-13).

Although there is some discretion involved in the judgment of exactly when sensitivity to further load reductions becomes low, there is a general decrease in sensitivity when the red area is low. One percent is a relatively consistent level at which sensitivity decreases significantly across many of the principal designated use-segments used for decision making in the Chesapeake Bay TMDL (Table I-2). At the nonattainment values of 1 percent (or less), there is a significant drop off in the sensitivity—further reduction in DO criteria nonattainment—of these designated use-segments to further load reductions. The analysis system is not sensitive to the effects of further load reductions at the 1 percent or less nonattainment level. This finding is fully consistent with findings from the parallel analysis summarized in Table I-1 for a wider array of designated use-segments.

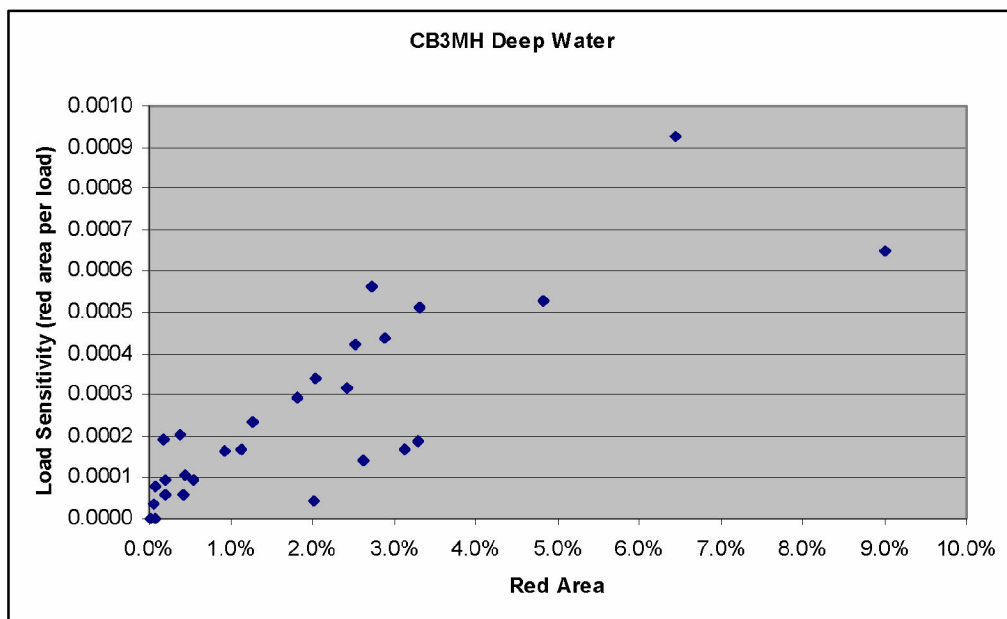


Figure I-6. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB3MH deep-water.

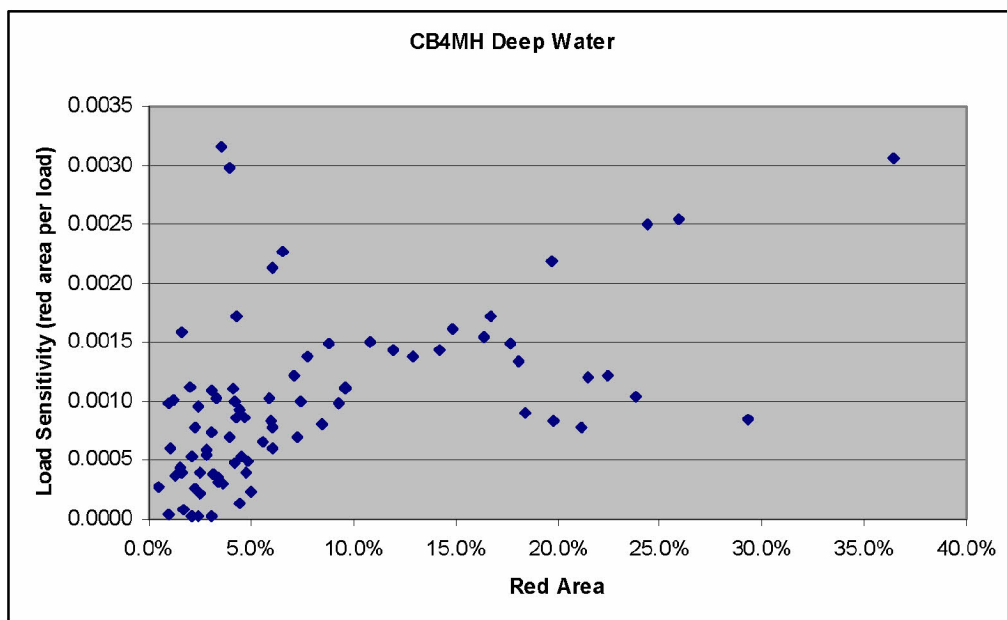


Figure I-7. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB4MH deep-water.



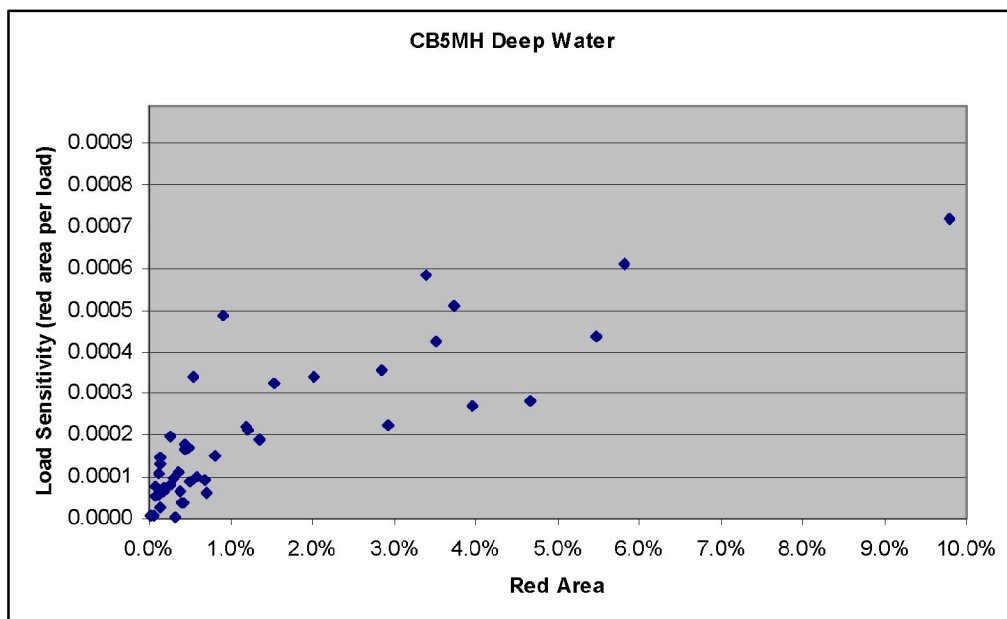


Figure I-8. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB5MH deep-water.

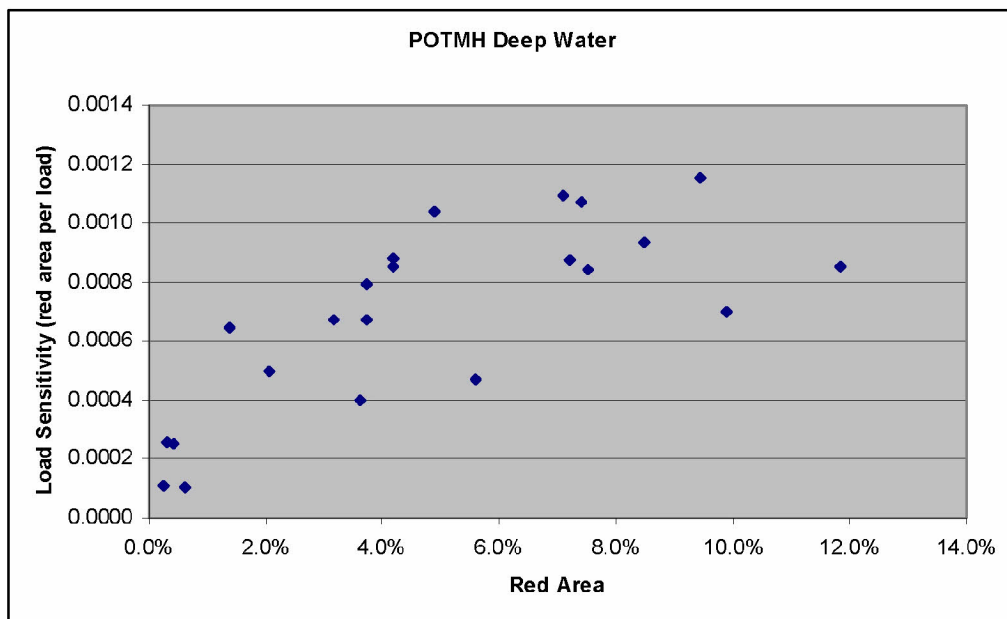


Figure I-9. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment POTMH deep-water.

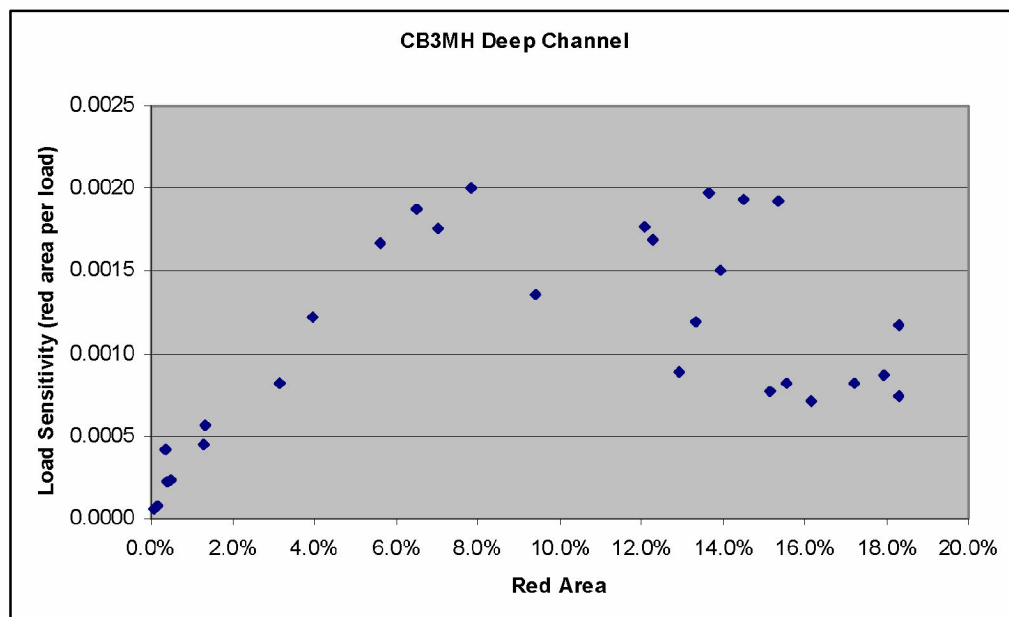


Figure I-10. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB3MH deep-channel.

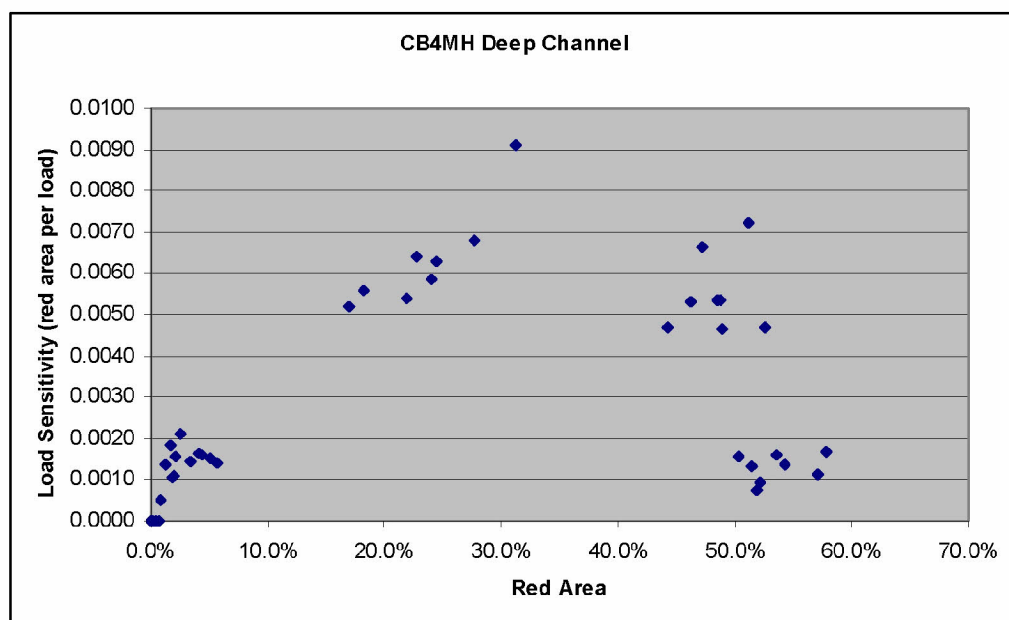


Figure I-11. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB4MH deep-channel.

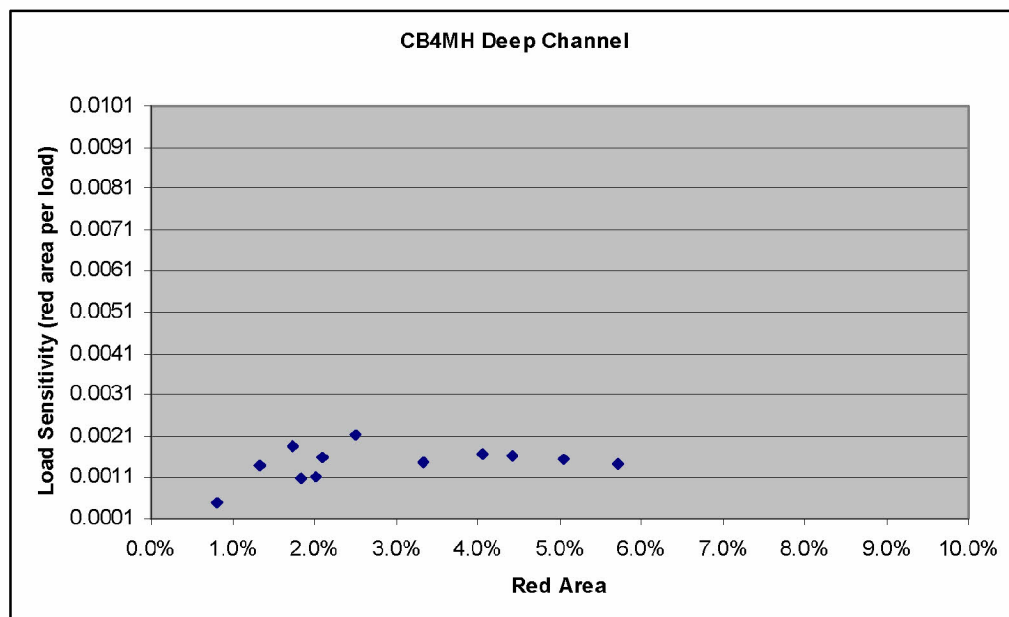


Figure I-12. Expanded view of the Figure I-11 focusing down on the 0-10% red area for segment CB4MH deep-channel to illustrate the drop off in sensitivity at the 1-1.5% of red area.

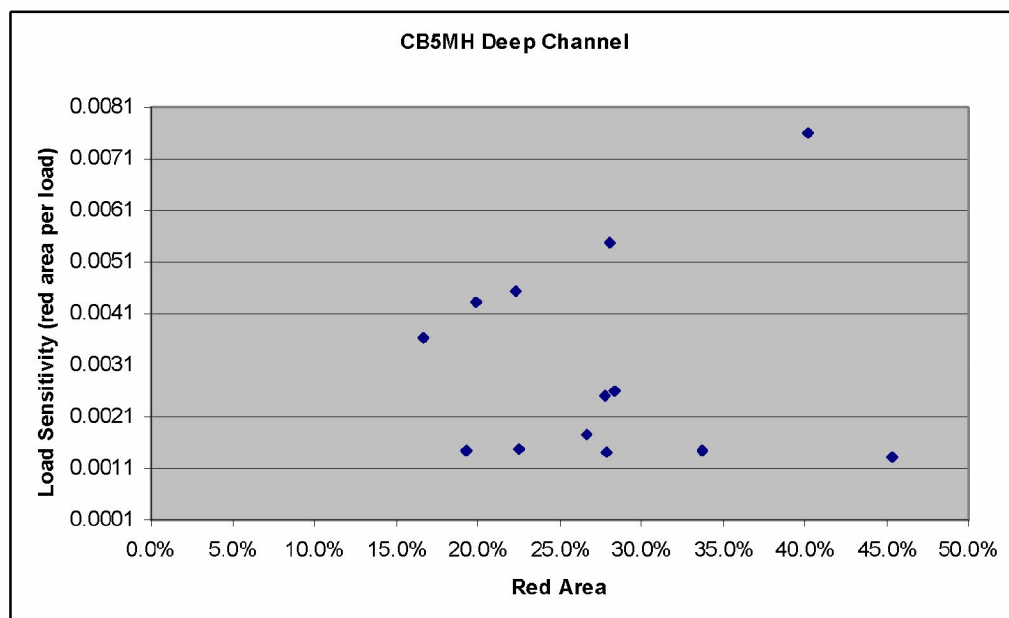


Figure I-13. Load sensitivity (unallowable DO criteria exceedances per load unit) vs. red area (unallowable DO criteria exceedances) for designated use-segment CB5MH deep-channel.

**Table I-2. Summary of findings from the analysis of red area with low sensitivity to load reductions for the Chesapeake Bay designated use**

Chesapeake Bay segment	Designated use	Red area with low sensitivity to load reductions (%)
CB3MH	Deep-water	0.2
CB4MH	Deep-water	0
CB5MH	Deep-water	1
POTMH	Deep-water	1
CB3MH	Deep-channel	1-1.5
CB4MH	Deep-channel	1
CB5MH	Deep-channel	N/A

Sources: Figures I-6 through I-13 in this appendix

### Water Clarity Criteria

Only one segment displayed a small, yet persistent percentage of model projected water clarity/submerged aquatic vegetation (SAV) criteria nonattainment over a range of reduced nitrogen and phosphorus loads—the Appomattox River segment (APPTF) in Virginia’s James River Basin. In the case of that segment, no observed SAV has been mapped since the early 1970s, but historical acreages were observed back in the 1950s. That tidal fresh segment (salinities from 0 to 0.5 ppt) was one of the very few tidal fresh segments that did not exhibit a positive response (increased water clarity, increased SAV acreage) to model simulated reductions in nitrogen, phosphorus, and sediment. For the reasons unique to this segment, EPA considered 1 percent nonattainment of the water clarity/SAV criteria in attainment for the Bay segment’s shallow water bay grass designated use for purposes of developing the Bay TMDL.

### Chlorophyll *a* Criteria

In the case of assessment of the chlorophyll *a* criteria in the tidal James River in Virginia, there was very limited evidence of a reduced sensitivity when approaching the criteria values as compared with the suite of DO criteria as described above for across multiple designated uses and segments. As illustrated in Figure I-14, there is a clear, positive response to reduced nitrogen and phosphorus loads, with a stepwise flattening of the response approaching full attainment. In developing the James River basin allocations under the Bay TMDL, the vast majority of the spring and summer season 3-year periods came into full attainment at the established nitrogen and phosphorus allocations of 23.5 million pounds of nitrogen per year and 2.35 million pounds of phosphorus per year (see Section 6.2.3 and Appendix O). EPA considered 1 percent nonattainment of the applicable segment and season-specific chlorophyll *a* criteria in attainment for only a limited number of segment/season/3-year period combinations given the evidence, though limited, of reduced sensitivity when approaching full attainment of the criteria values.



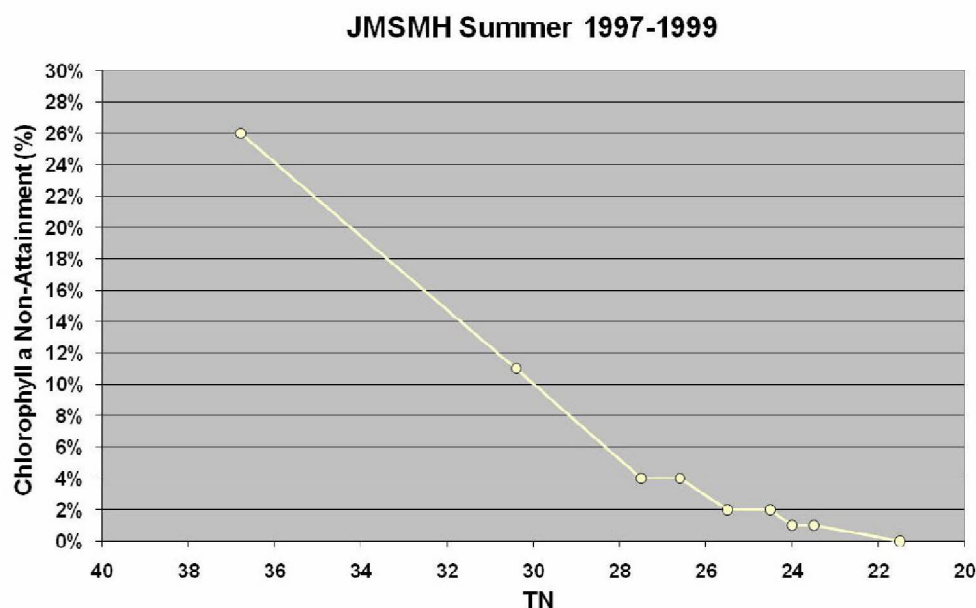


Figure I-14. Example of the middle James River segment's summer chlorophyll *a* criteria nonattainment results from a wide range of TN and TP loading Chesapeake Bay Water Quality Model scenarios.

## Application in Development of the Bay TMDL

### DO Criteria

Because such findings have been observed in a wide variety of different segments across all three designated uses—open-water, deep-water, and deep-channel—and confirmed through an independent analysis, DO criteria nonattainment percentages rounded to 1 percent were considered in attainment for that Bay segment's designated use for purposes of developing the Bay TMDL. For those designated use-segments for which a jurisdiction has adopted a restoration variance that sets attainment at a percentage of the non-allowable criteria exceedances, the 1 percent nonattainment described above does not apply to assessment of the restoration variance percentage. For example, Maryland's designated use-segment CB4MH deep water has a restoration variance of 7 percent. Chesapeake Bay Water Quality Model-based criteria attainment assessment results showing 8 percent nonattainment would still be considered in nonattainment.

### Chlorophyll *a* and Water Clarity/SAV Criteria

In the case of the chlorophyll *a* criteria assessments, EPA considered nonattainment percentages rounded to 1 percent in attainment only for a select set of segment/season/3-year period combinations given the more limited evidence of reduced sensitivity when approaching full attainment of the criteria values compared with DO. Only one Bay segment had unique circumstances that supported EPA's considering water clarity/SAV criteria nonattainment percentages rounded to 1 percent to be in attainment.

## References

USEPA (U.S. Environmental Protection Agency). 2003. Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries. EPA 903-R-03-002. Region 3 Chesapeake Bay Program Office, Annapolis, MD.